Impact of Nuclear Data Uncertainties in the Phase-1B Benchmark

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1. Introduction

Accurate control over **the spent nuclear fuel content** is essential for its safe and optimized transportation, storage and management. Consequently, the reactivity of spent fuel and its isotopic content must be accurately determined.

Nowadays, isotopic evolution throughout irradiation and decay periods can be predicted using **powerful codes and methodologies**.

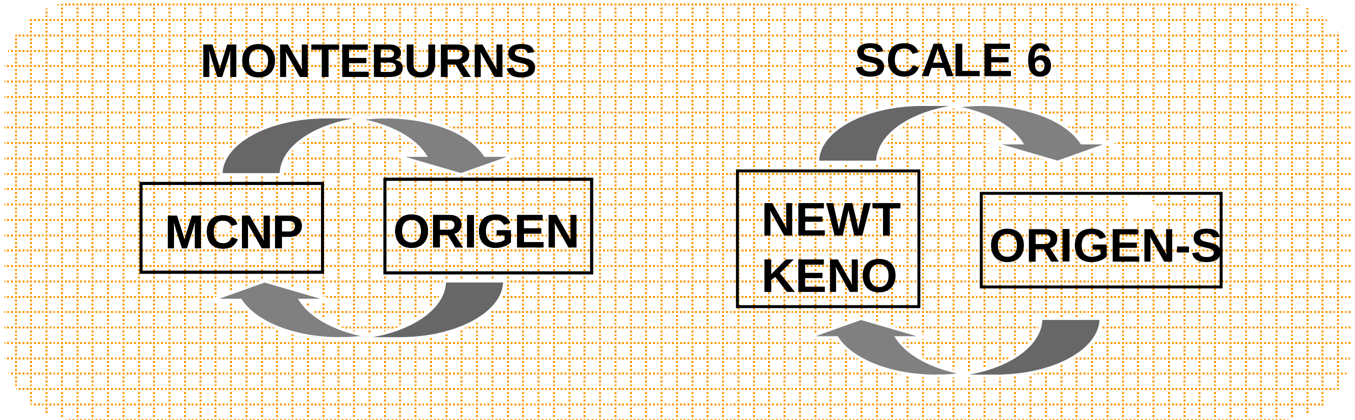


Figure 1.
Computing systems coupling neutron transport and isotopic inventory codes

In order to have a realistic confidence level in the prediction of spent fuel isotopic content, it is desirable to determine **how uncertainties affect isotopic prediction calculations** by quantifying their associated uncertainties:

- ✓ *irradiation history, calculation models-coupling, …*
- ✓ ***nuclear data: cross section, fission yields and decay data***

2. Phase I-B Burnup Credit Benchmark: "Description and background"

- With the intention of providing a base for **the intercomparison of computer codes, methods and data** applied in spent nuclear fuel analysis, well-defined calculational benchmarks have been established by the NEA Burnup Credit Working Group.

- **The Phase I-B** (see Ref.) was proposed to provide a comparison of the ability of different code systems and data libraries to predict isotopic concentrations. The participating organizations analyzed with their different codes and methodologies the same **LWR pin-cell problem** for three increasing burnups (CASE A - 27 GWd/TMU, CASE B - 37 GWd/TMU and CASE C - **44 GWd/TMU**).

- All the participants provided (see Ref.) isotopic concentrations:
  - **within10% agreement with meas.** values for actinides(12) and fission products(15)
  - within 11% agreement about the average
  - most deviations are less than 10% and many others less than 5%
  - above 10% deviations are found for **Sm149, Sm151 and Gd155** and were believed to result from inconsistencies in cross-section and fission yield data

Ref. Phase I-B: DeHart M.D., Brady M.C., Parks C.V., OECD/NEA Burnup Credit Calculational Criticality Benchmark Phase I-B Results, ORNL-6901, Oak Ridge National Laboratory, June 1996

2.1 Phase I-B Burnup Credit Benchmark: "Revisiting the problem"

A recent comparison of this Benchmark was performed **at UPM** with different burnup codes

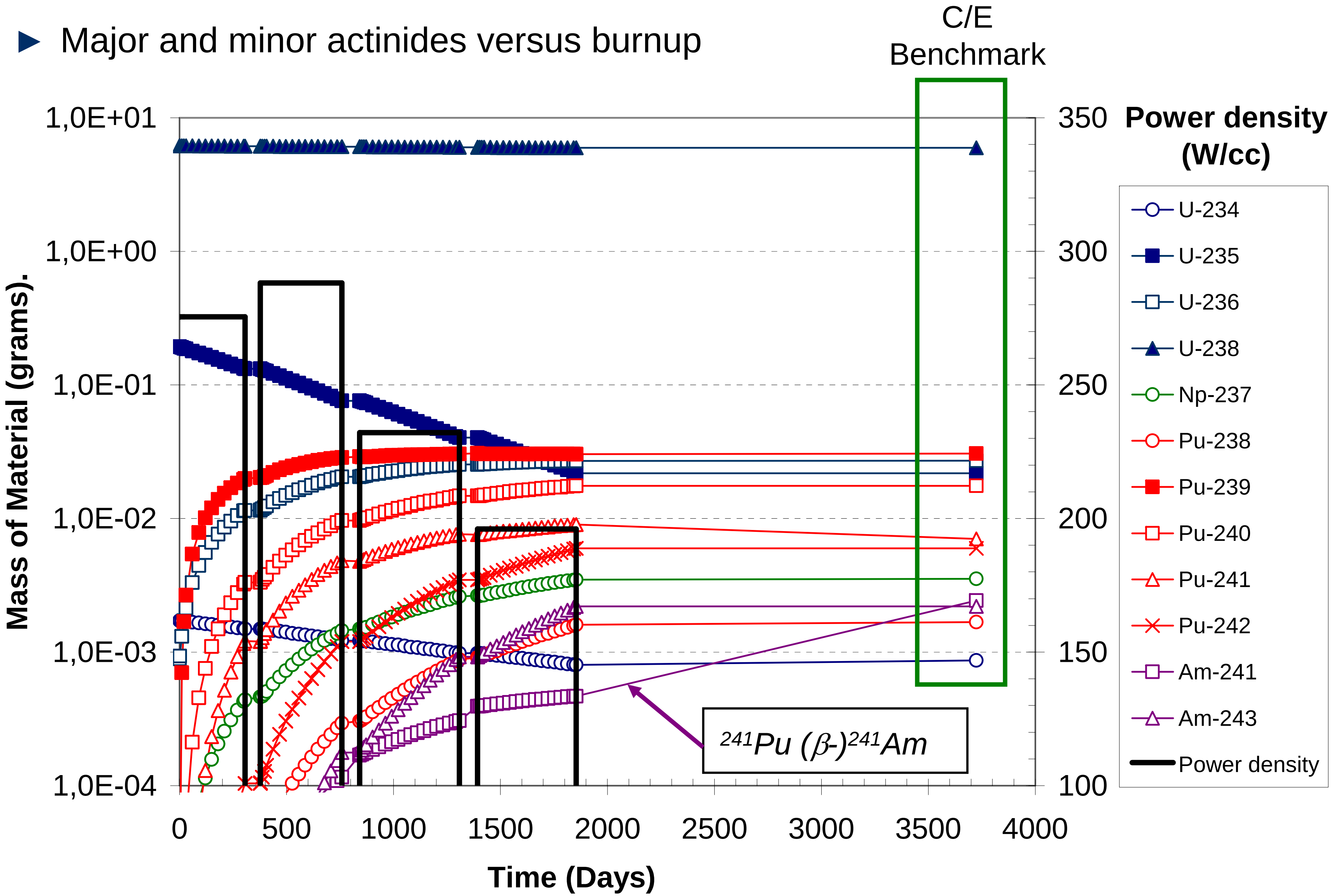
- **WIMSD5**: *Deterministic Multigroup Reactor Lattice Calculations, distributed by the NEA/OECD*
- **SERPENT**: *Continous-energy Monte Carlo Reactor Physics Burnup Calculation Code*
- **SCALE6.0/TRITON**: *Two-Dimensional Transport and Depletion Module*
- **MONTEBURNS2.0**: *An Automated, Multi-Step Monte Carlo Burnup Code System*
- **MCNP-ACAB**: *An UPM development based on MONTEBURNS System*

Main conclusions:

- These codes are **within 10% agreement** with measured and average values for all the isotopes except for actinides: **Pu238, Am243**, and for light elements: **Ag109, Sm149, Sm151 and Gd155**
- In CASE-A, 235U and Pu239 are predicted with a relative error below 3%
- A comparison using SERPENT code permits to appreciate the differences between JEFF-3.1.1 and ENDF/B-VII, as well as **a significant improvement with JEFF-3.1.1 for 243Am and 109Ag**
- SCALE 6.0 has a good agreement, better using CENTRM option
- **MONTEBURNS 2.0 and MCNP-ACAB** coupled system reproduce isotopes whose deviations from measured values are in good agreement with the rest of the codes

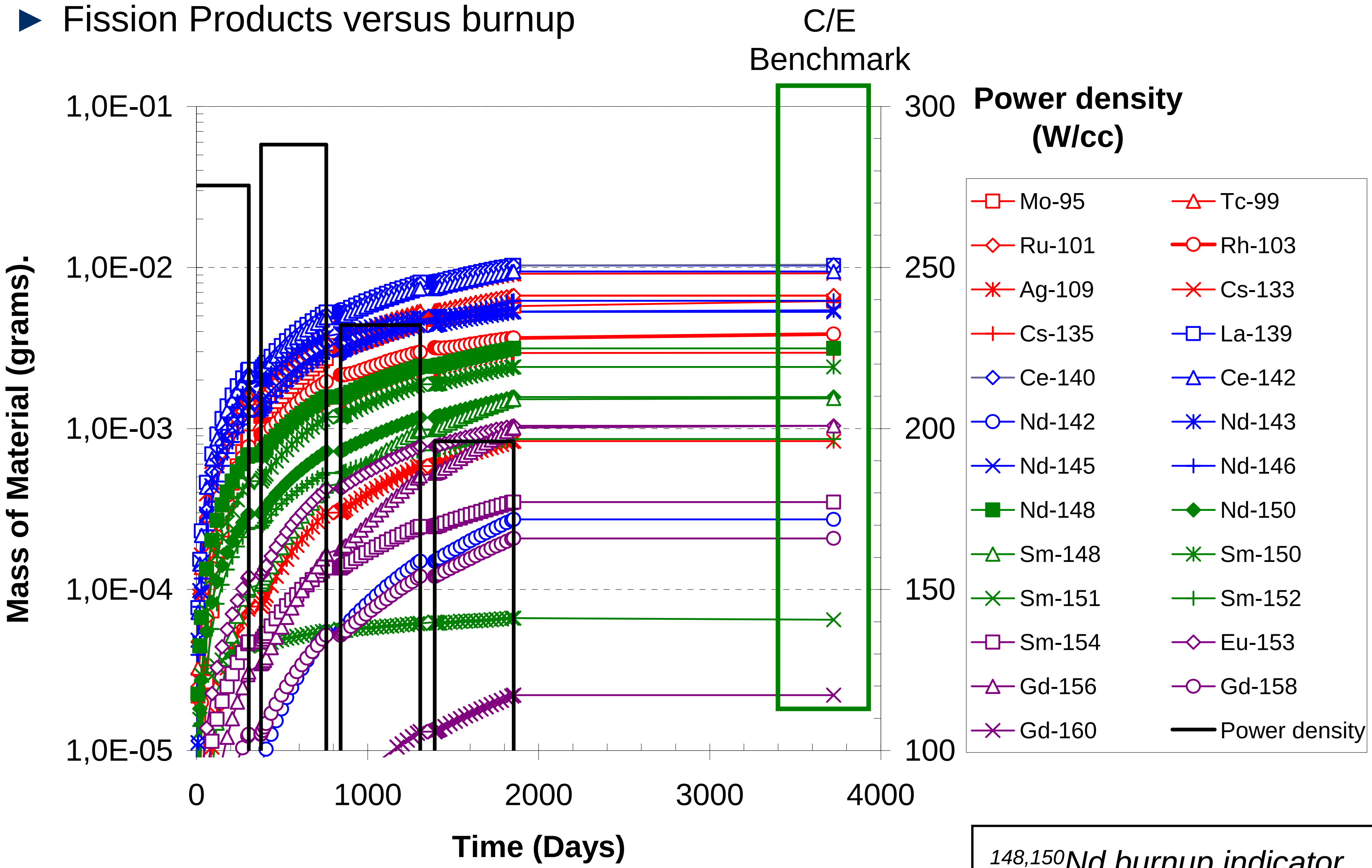
CASE C- 44 GWd/TMU: Actinides

- Major and minor actinides versus burnup



CASE C- 44 GWd/TMU: Fission Products

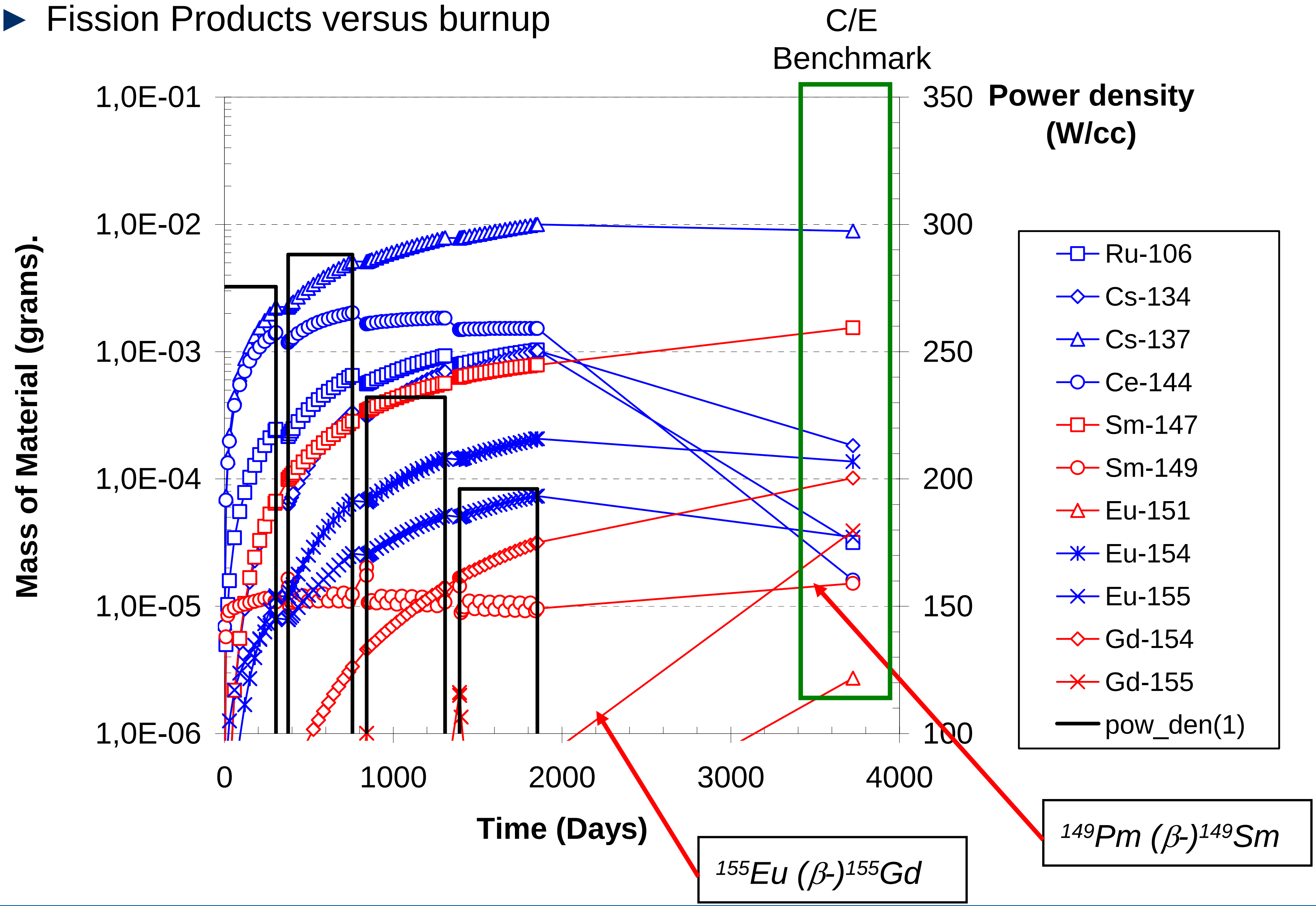
- Fission Products versus burnup



148,150Nd burnup indicator

CASE C- 44 GWd/TMU: Fission Products

▶ Fission Products versus burnup



2.1 Phase I-B Burnup Credit Benchmark: "Revisiting the problem"

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Table I. Comparison (C/E-1)*100% for different codes for the OECD/NEA Burnup Credit Benchmark Phase-1B (**CASE A**- 27.35 GWd/TU).

Isotope	WIMSD5	SCALE 6.0		SERPENT1.1.7		Monteburns2.0	MCNP+ACAB
	LIB1986	NITAWL LIB-44g	CENTRM LIB-238g	All ND taken from JEFF-3.1.1	All ND taken from ENDF/B-VII	ENDF/B-VII + PWRLIB	ENDF/B-VII + EAF2007 + JEFF-3.1.1 Decay&FY
^{234}U	-2.5	-0.8	0.8	-0.9	-0.9	0.8	0.8
^{235}U	-3.7	-3.0	-1.1	-3.2	-3.0	-2.7	-2.8
^{236}U	0.7	2.0	1.1	1.5	1.7	4.1	4.1
^{238}U	-0.6	-0.6	-0.6	-0.6	-0.6	1.5	1.5
^{237}Np	-4.1	3.5	-2.9	4.7	4.0	8.3	7.2
^{238}Pu	-36.4	-13.8	-20.2	-9.9	-12.6	-10.1	-13.6
^{239}Pu	-3.5	0.3	3.6	-3.1	-2.9	-0.4	-0.1
^{240}Pu	1.4	-1.3	0.4	-0.9	-1.7	0.4	0.4
^{241}Pu	-4.4	-4.1	-0.3	-2.5	-1.8	-0.9	-0.7
^{242}Pu	-9.6	-0.5	-3.0	1.4	-0.02	1.0	1.0
^{241}Am(*)	-3.9	-3.6	0.1	-4.0	-1.5	-1.4	0.3
^{243}Am(*)	-8.1	14.2	8.2	3.3	12.8	13.9	38.4

< 3%

< 3%

(*) Differences respect to the averaged of the calculated concentrations

2.1 Phase I-B Burnup Credit Benchmark: "Revisiting the problem: CASE A"

Table II. Comparison (C/E-1)*100% for different codes for the OECD/NEA Burnup Credit Benchmark Phase-1B (**CASE A**- 27.35 GWd/TU).

Isotope	WIMSD5	SCALE 6.0		SERPENT1.1.7		Monteburns2.0	MCNP+ACAB
	LIB1986	NITAWL LIB-44g	CENTRM LIB-238g	All ND taken from JEFF-3.1.1	All ND taken from ENDF/B-VII	ENDF/B-VII + PWRLIB	ENDF/B-VII + EAF2007 + JEFF-3.1.1 Decay&FY
^{95}Mo(*)	2.3	-0.5	-1.0	0.7	0.1	2.1	3.2
^{99}Tc (*)	2.0	0.2	-0.1	-1.5	-1.7	1.4	4.5
^{101}Ru(*)	-0.3	1.3	0.5	2.2	1.3	3.0	4.7
^{103}Rh(*)	-4.9	2.9	3.2	2.5	2.8	4.6	7.4
^{109}Ag(*)	-9.6	-12.9	-11.7	-6.7	-39.1	0.4	10.4
^{133}Cs	-0.5	0.9	0.1	-1.2	0.1	2.6	2.7
^{143}Nd	3.0	0.1	0.0	-0.8	-0.6	2.0	2.5
^{145}Nd	-1.2	-0.4	-1.5	0.7	-0.8	1.6	2.1
^{147}Sm(*)	-4.1	3.2	6.8	5.5	5.3	6.6	3.4
^{149}Sm	-19.4	-33.4	-34.9	-36.5	-35.2	-35.1	-34.6
^{150}Sm	-3.3	-6.7	-1.4	-4.1	-5.5	0.2	-4.3
^{151}Sm(*)	45.7	-0.4	-18.8	-18.3	-19.9	-11.4	-19.4
^{152}Sm	12.1	12.1	-1.2	-0.7	-2.6	7.8	1.3
^{153}Eu	-13.6	-2.3	1.2	2.0	1.8	10.2	4.1
^{155}Gd(*)	-	-52.7	-31.0	-29.2	-30.6	-28.5	-29.9

(*) Differences respect to the averaged of the calculated concentrations

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2.2 Phase I-B Burnup Credit Benchmark: "Revisiting the problem CASE A, B & C"

Table III. Comparison (C/E-1)*100% for different codes for the OECD/NEA Burnup Credit Benchmark Phase-1B (**CASE A, B and C**).

Isotope	MCNP+ACAB		
	CASE A 27.35 GWd/TMU	CASE B 37.12 GWd/TMU	CASE C 44.34 GWd/TMU
^{234}U	0.8	-3.4	0.3
^{235}U	-2.8	-8.5	-14.6
^{236}U	4.1	2.5	1.9
^{238}U	1.5	-0.2	0.0
^{237}Np	7.2	13.4	4.9
^{238}Pu	-13.6	-13.6	-13.3
^{239}Pu	-0.1	-2.3	-2.3
^{240}Pu	0.4	-2.8	-4.0
^{241}Pu	-0.7	-3.4	-4.4
^{242}Pu	1.0	0.1	-1.3
^{241}Am(*)	0.3	-1.3	-1.0
^{243}Am(*)	38.4	47.6	59.2

Isotope	MCNP+ACAB		
	CASE A 27.35 GWd/TMU	CASE B 37.12 GWd/TMU	CASE C 44.34 GWd/TMU
^{95}Mo(*)	3.2	1.2	1.5
^{99}Tc (*)	4.5	3.3	3.4
^{101}Ru(*)	4.7	2.6	2.8
^{103}Rh(*)	7.4	6.3	7.3
^{109}Ag(*)	10.4	10.6	11.9
^{133}Cs	2.7	1.7	2.9
^{135}Cs	4.6	-1.2	-4.9
^{143}Nd	2.5	-0.4	-1.5
^{145}Nd	2.1	-0.8	-1.2
^{147}Sm(*)	3.4	2.1	3.2
^{149}Sm	-34.6	-32.5	-55.4
^{150}Sm	-4.3	0.8	-7.4
^{151}Sm(*)	-19.4	-23.0	-23.0
^{152}Sm	1.3	2.8	-1.4
^{153}Eu	4.1	8.5	-2.5
^{155}Gd(*)	-29.9	-35.6	-38.4

(*) Differences respect to the averaged of the calculated concentrations

3. Sources of uncertainties in a depletion calculation

The influence of all these sources should be investigated in order to understand and quantify the uncertainties associated with computer code predictions for spent fuel isotopics:

$$\frac{dN}{dt} = [\lambda]N + \left[\sigma^{eff}\right]\cdot\Phi N + \left[(\gamma\sigma_{fiss})^{eff}\right]\cdot\Phi N = A\cdot N$$

$$N = N\left(\lambda, \sigma^{eff}, \Phi\right) = N(\lambda, \gamma, \sigma^{g}, \phi^{g}(E), \Phi)$$

- Uncertainties in decay constants: Δ_{λ}
- Uncertainties in one-group effective xs: $\Delta_{\sigma^{eff}}$

$$\sigma^{eff} = \sum_{g}\sigma^{g}\phi^{g} \Big/ \sum_{g}\phi^{g}$$

  - uncertainties in the evaluated nuclear xs data: $\Delta\sigma^{g}$

  - uncertainties in the flux spectrum obtained from the transport calculation: $\Delta\phi^{g}$

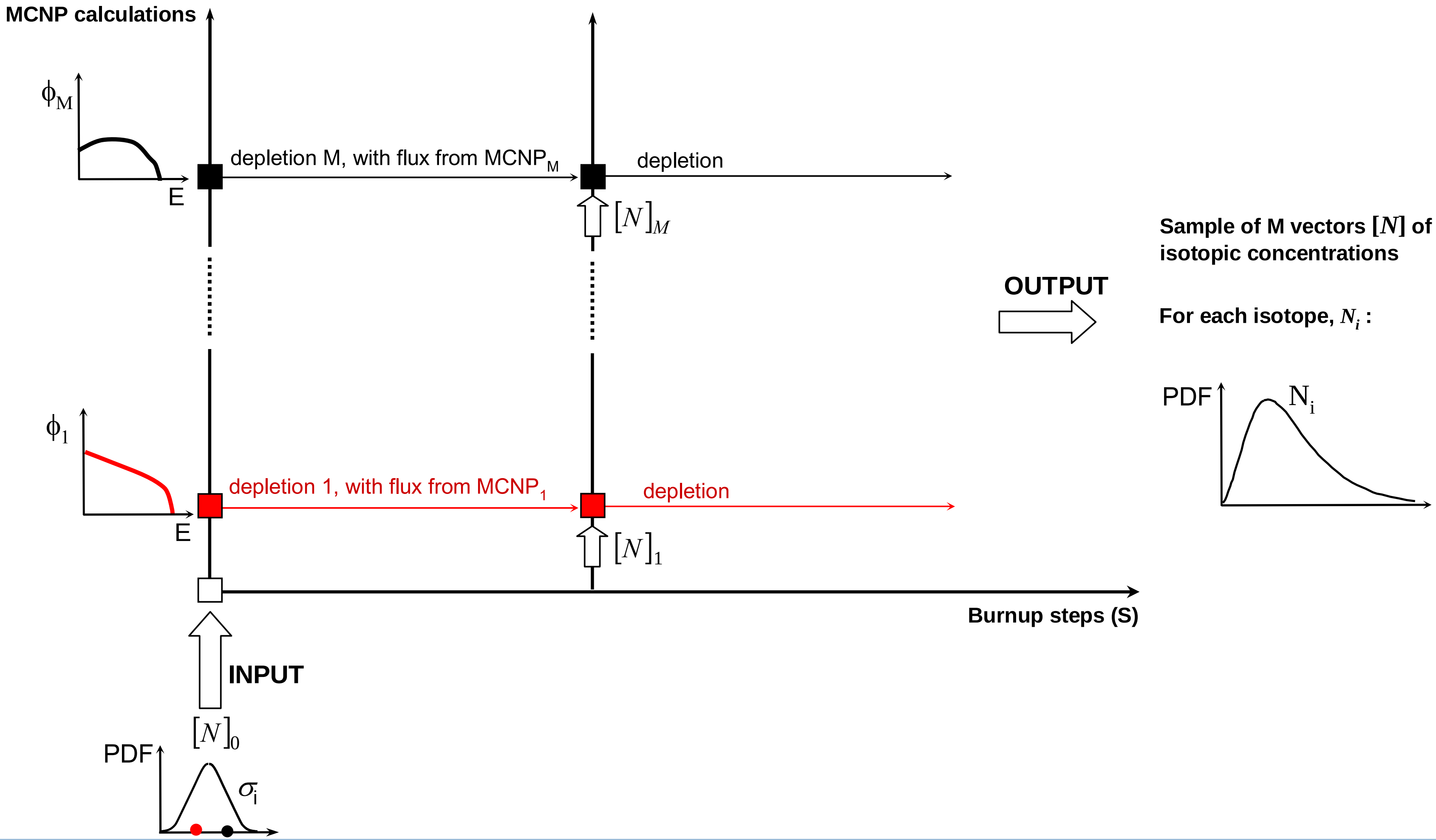
- Uncertainties in the integrated neutron flux: $\Delta\Phi$

3.1 Propagation of uncertainties in burn-up calculations: "Brute Force MC"

"Brute force" random sampling method

Same sequence that the coupled calculation scheme to infer an error propagation procedure throughout the time

Simultaneous random sampling of the PDF of all the input parameters



3.1 Propagation of uncertainties in burn-up calculations: "S/U Analysis"

Sensitivity/ Uncertainty Analysis (S/U)

Procedure based on a **first order Taylor** series approach

$$N_i(\sigma^{eff}) = N_i(\hat{\sigma}^{eff}) + \sum_{j=1}^{R} \boxed{\left[\frac{\partial N_i}{\partial \sigma_j}\right]_{\hat{\sigma}^{eff}}} \boxed{\left(\sigma_j^{eff} - \hat{\sigma}_j^{eff}\right)} + \ldots$$

Sensitivity coefficient ρ_{ij}

ε_j error in the 1-G effective xs

$$\sigma_j^{eff} = \sum_g \sigma_j^g \phi^g$$

$$\varepsilon_j = \sum_{g=1}^{G} \phi^g \left(\sigma_j^g - \hat{\sigma}_j^g\right) + \sum_{g=1}^{G} \sigma_j^g \left(\phi^g - \hat{\phi}^g\right) = \phi^T \boxed{\varepsilon_{\sigma_j}} + \sigma_j^T \boxed{\varepsilon_\phi}$$

errors due to uncertainties in the multigroup xs $\left[COV_{\sigma_j}\right]$

to be processed from the uncertainty libraries

errors due to uncertainties in the multigroup flux spectrum $\left[COV_\phi\right]$

to be obtained from a single MCNP calculation

3.1 Propagation of uncertainties in burn-up calculations : “S/U Analysis”

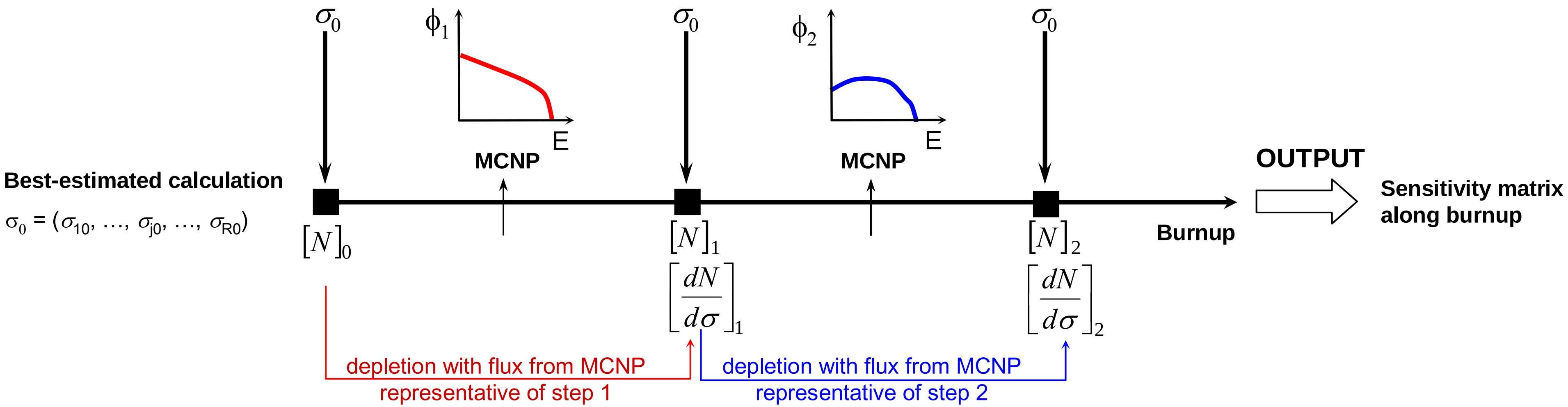
Sensitivity/ Uncertainty Analysis (S/U)

$$N\left(\sigma^{eff}\right) - N\left(\hat{\sigma}^{eff}\right) \approx \boldsymbol{S}\,\varepsilon$$

$$var\,N \approx \boldsymbol{S}\left[COV_{\sigma^{eff}}\right]\boldsymbol{S}^{\boldsymbol{T}} \approx \boldsymbol{S}\left\{\underbrace{\begin{bmatrix} \ddots & & 0 & \\ 0 & \hat{\phi}^{T}\left[COV_{\sigma_j}\right]\hat{\phi} & & \\ & & & \ddots \end{bmatrix}}_{} + \underbrace{\begin{bmatrix} \ddots & & 0 & \\ 0 & \hat{\sigma}_j{}^{T}\left[COV_{\phi}\right]\hat{\sigma}_j & & \\ & & & \ddots \end{bmatrix}}_{}\right\}\boldsymbol{S}^{\boldsymbol{T}}$$

Propagates the multigroup xs uncertainties when there is no statistical flux errors

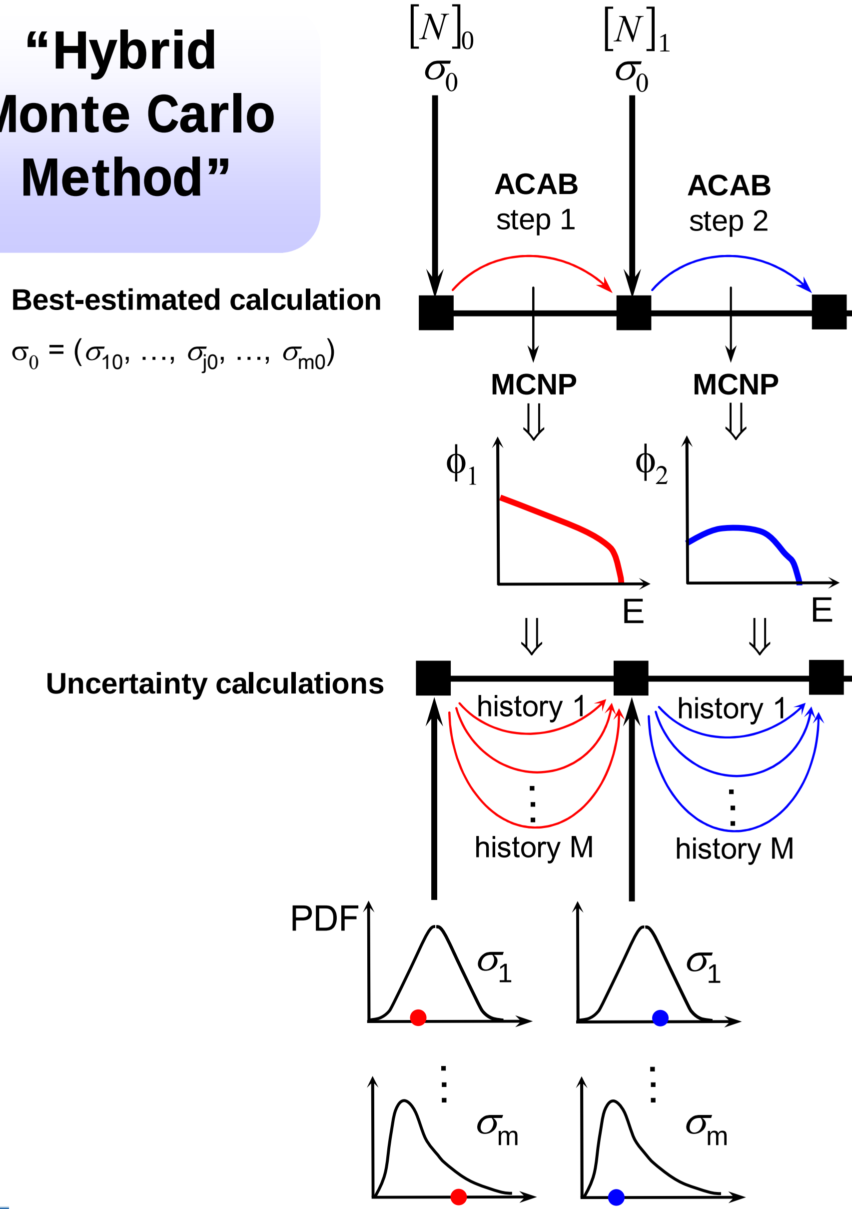
Propagates statistical flux errors when there is no multigroup xs covariances

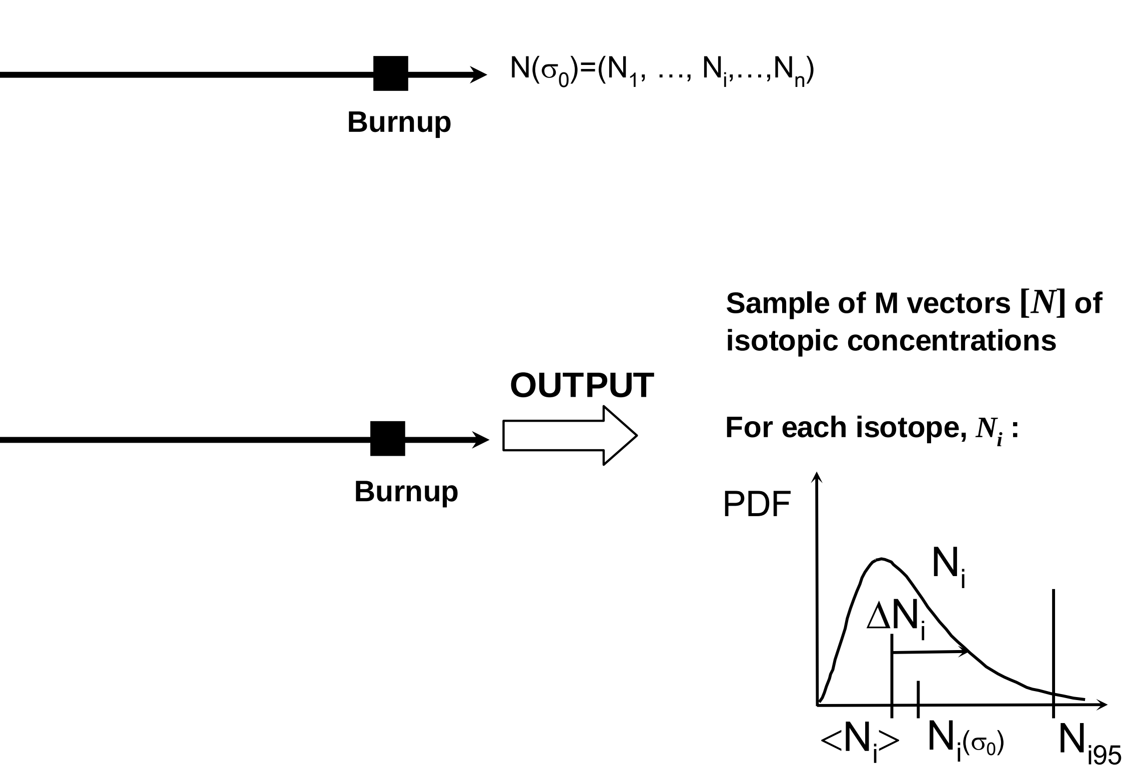


3.1 Propagation of uncertainties in burn-up calculations: “Hybrid Method”

“Hybrid Monte Carlo Method”

Reference: *“Propagation of statistical and nuclear data uncertainties in Monte Carlo burn-up calculations”, N. Garcia-Herranz, O. Cabellos, J. Sanz, J.. Juan, J. C. Kuijper, Annals of Nuclear Energy, 35 (2008)*





This **MC Hybrid Method** will be used to account for the impact in inventory calculations of uncertainties in the basic nuclear data (cross-section, decay data and fission yields) along the consecutive spectrum-depletion steps

3.2 Propagation of uncertainties in burn-up calculations: "Phase I-B Benchmark"

Table IV. MCNP-ACAB **calculated uncertainties in actinides** due to cross-section & decay data uncertainties for Phase-1B OECD/NEA Burnup Credit Benchmark. (CASE C- 44.34 GWd/TMU)

- Uncertainties due to **cross-sections**:
  - For major actinides, the uncertainty remains below 2%. It increases for minor actinides
  - Lower uncertainties using SCALE6.0/COVA
  - Lower uncertainties for Cm isotopes using EAF2010/UN
- Uncertainties due to **decay data** remain very low, except for 243Cm with 0.8% (relative error of Cm243 half-life is 6.7%)

Isotope	Decay Data	Cross-section		
	JEFF-3.1.1	EAF2007/UN	EAF2010/UN	SCALE6.0/COVA
233U	0.2	1.4	0.6	1.3
234U	0.1	2.5	0.8	1.8
235U	0.0	0.8	0.1	0.2
236U	0.0	0.4	0.4	0.2
238U	0.0	0.1	0.1	0.0
237Np	0.0	0.7	0.6	0.5
238Pu	0.0	0.9	2.4	0.3
239Pu	0.0	1.5	0.5	0.5
240Pu	0.0	1.8	1.1	0.5
241Pu	0.1	1.6	0.9	0.4
242Pu	0.0	1.2	1.1	0.7
241Am	0.2	1.5	0.9	0.4
243Am	0.0	1.9	1.3	1.7
242Cm	0.4	1.5	3.1	0.7
243Cm	0.8	4.6	4.4	3.2
244Cm	0.1	2.0	1.4	1.8
245Cm	0.0	3.1	1.6	3.8
246Cm	0.0	4.0	1.8	2.7
247Cm	0.0	4.5	2.1	3.2
248Cm	0.0	5.8	2.9	3.7
250Cf	0.2	7.5	4.6	4.7
251Cf	0.1	7.9	5.0	5.2
252Cf	0.4	6.7	4.6	4.4

(in grey color) Phase I-B selected actinides

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3.2 Propagation of uncertainties in burn-up calculations: "Phase I-B Benchmark"

Table VI. MCNP-ACAB calculated uncertainties in light elements due to cross-section uncertainties for Phase-1B OECD/NEA Burnup Credit Benchmark. (CASE C- 44.34 GWd/TMU)

Isotope	Fission Yields JEFF-3.1.1	Decay Data JEFF-3.1.1	Cross-section		
			EAF2007/UN	EAF2010/UN	SCALE6.0/COVA
95Mo	4,5	0,0	0,5	0,4	0,2
99Tc	1,2	0,0	0,4	0,4	0,2
101Ru	1,2	0,0	0,4	0,3	0,2
106Ru	1,8	0,9	0,5	0,5	0,2
103Rh	1,3	0,0	1,9	0,7	0,3
109Ag	1,3	0,0	2,3	2,3	0,3
133Cs	0,9	0,0	0,4	0,3	0,2
134Cs	0,9	0,0	1,7	1,1	0,8
135Cs	0,9	0,0	1,1	0,7	0,4
137Cs	1,2	0,0	0,4	0,3	0,2
139La	1,2	0,0	0,4	0,3	0,1
140Ce	1,2	0,0	0,3	0,3	0,1
142Ce	1,3	0,0	0,4	0,3	0,1
144Ce	1,7	0,4	0,5	0,5	0,2
142Nd	1,3	0,0	0,8	1,6	0,5
143Nd	1,1	0,0	0,5	0,9	0,3
145Nd	1,1	0,0	0,4	0,3	0,2
146Nd	0,8	0,0	0,4	0,3	0,2
148Nd	0,9	0,0	0,4	0,3	0,2
150Nd	1,4	0,0	0,4	0,3	0,2

(in grey color) Phase I-B selected actinides

- **Uncertainties due to decay data** remain very low, except for **151Eu - 7.1% rel. err.** (it is generated by β-decay of Sm151 with a half-life relative error of 6.7%)

- **Uncertainties due to fission yields** remain below 5%: 95Mo with 4.5% (high sensitivity to 95Zr FY) and 149Sm with 4.7% (high sensitivity to 149Pm FY)

3.2 Propagation of uncertainties in burn-up calculations: “Phase I-B Benchmark”

Table VI. MCNP-ACAB calculated uncertainties in light elements due to cross-section uncertainties for Phase-1B OECD/NEA Burnup Credit Benchmark. (CASE C- 44.34 GWd/TMU)

Isotope	Fission Yields JEFF-3.1.1	Decay Data JEFF-3.1.1	Cross-section		
			EAF2007/UN	EAF2010/UN	SCALE6.0/COVA
147Sm	1,2	0,0	1,0	0,4	1,0
148Sm	1,3	0,0	0,7	0,4	0,4
149Sm	4,7	0,0	11,2	2,5	4,5
150Sm	0,8	0,0	0,8	0,4	0,7
151Sm	2,7	0,3	2,2	2,4	2,1
152Sm	0,8	0,0	1,6	0,6	0,7
154Sm	1,0	0,0	0,4	0,4	0,2
151Eu	2,7	7,1	2,2	2,3	2,1
153Eu	0,7	0,0	4,6	3,2	0,5
154Eu	0,7	0,0	10,6	7,6	3,1
155Eu	1,3	0,2	17,3	7,5	4,0
154Gd	0,7	0,0	7,7	5,6	2,4
155Gd	1,3	0,2	17,3	7,5	4,0
156Gd	0,9	0,0	5,2	1,9	0,5
158Gd	1,3	0,0	10,2	1,0	0,5
160Gd	2,7	0,0	0,6	0,5	0,2

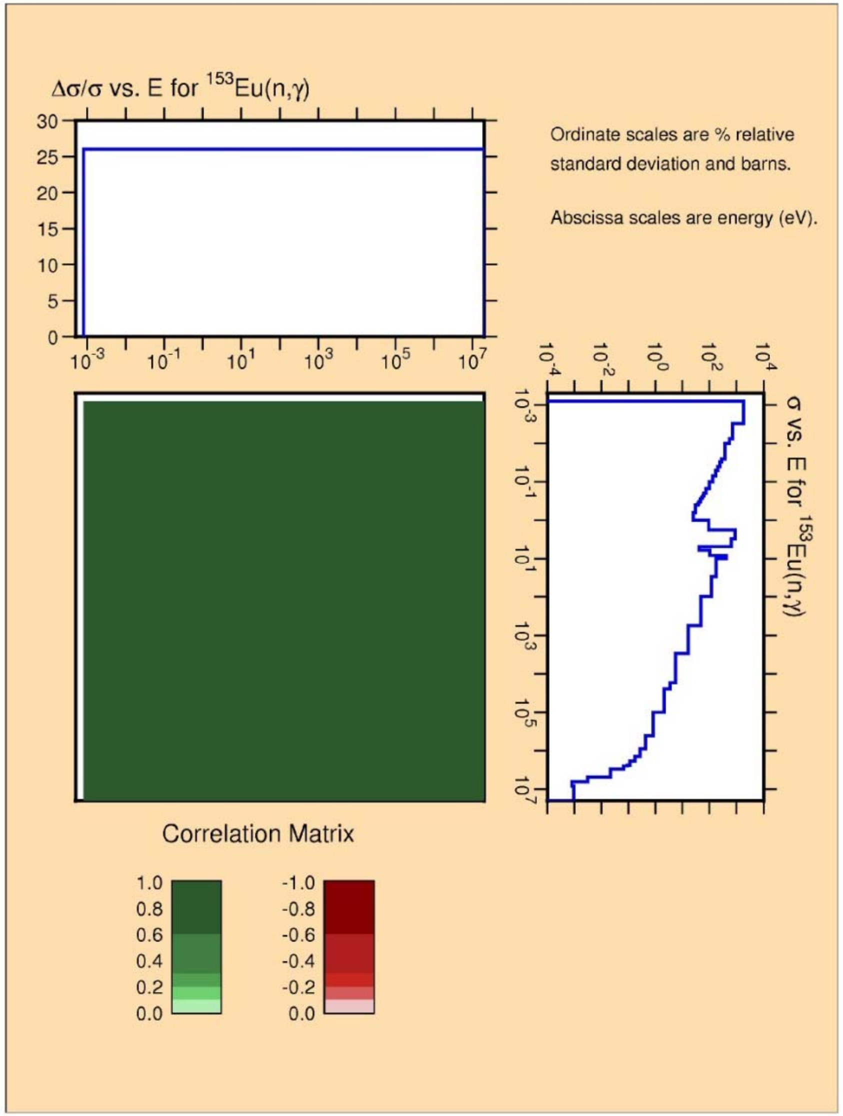
(in grey color) Phase I-B selected actinides

- **Higher uncertainties due to cross-section data** showing a good agreement between EAF2010/UN and SCALE6.0/COVA

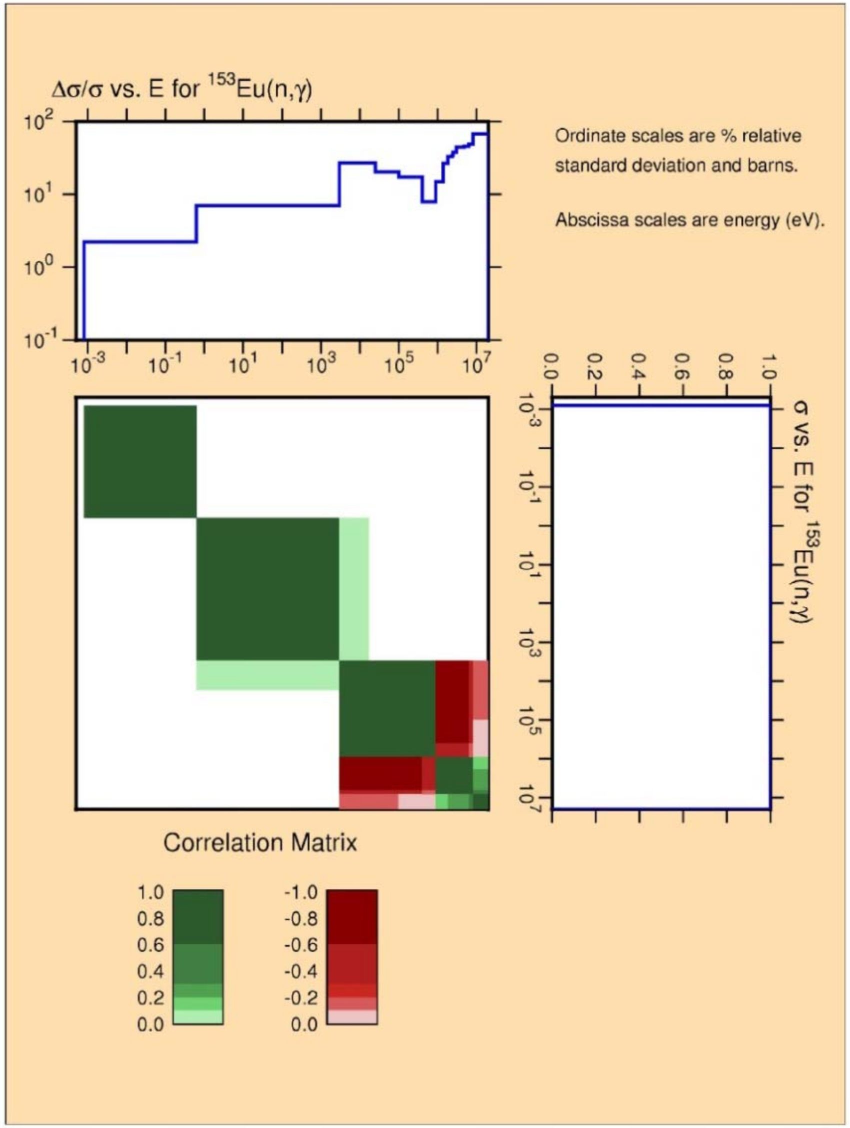
- **155Gd:** it is generated by β-decay of 155Eu, with higher sensitivities to **155Eu and 153Eu (n,γ)** reactions, and 155Eu- fission yield
- **149Sm:** important contribution by β-decay of 149Pm, with higher sensitivities to **149Sm (n,γ)** reaction and 149Pm-fission yield

Cross-section Uncertainties: e.g. 153Eu (n,γ)

EAF2010/UN

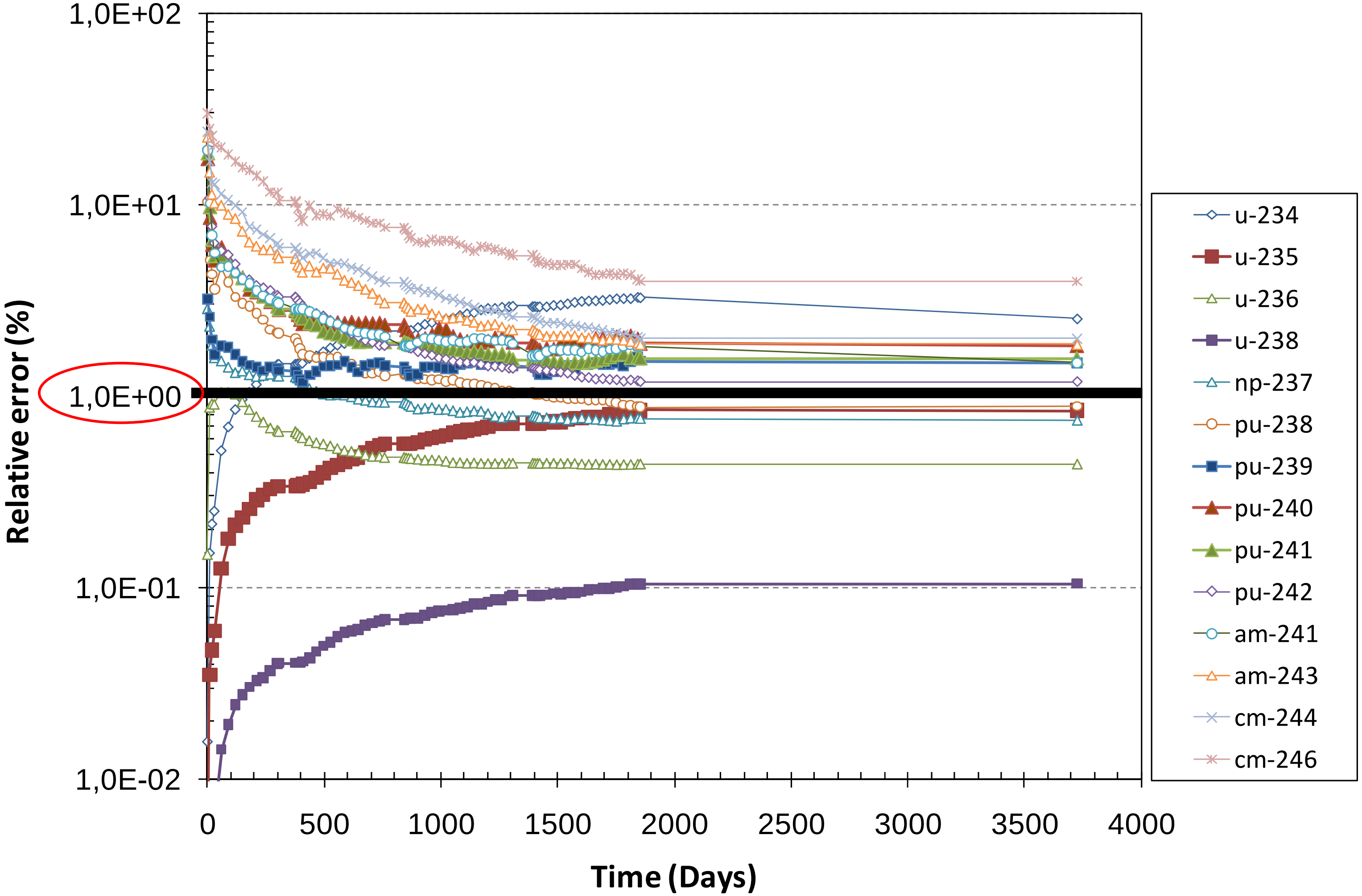


SCALE6.0/COVA



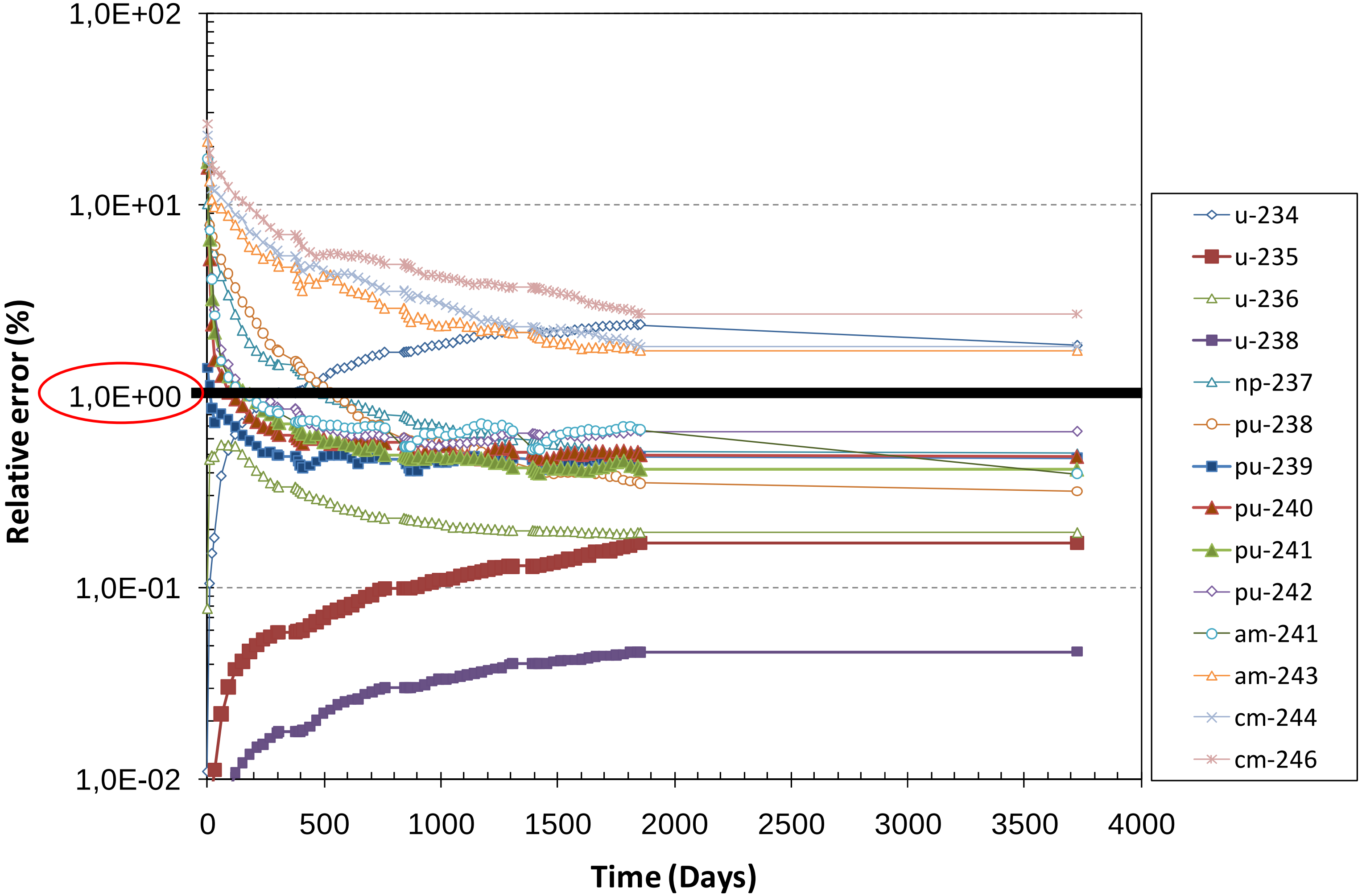
ΔN/N due to XS: Actinides

- ΔN/N (%) predicted with Hybrid Monte Carlo Method due to **uncertainties in XSs** (EAF2007/UN)



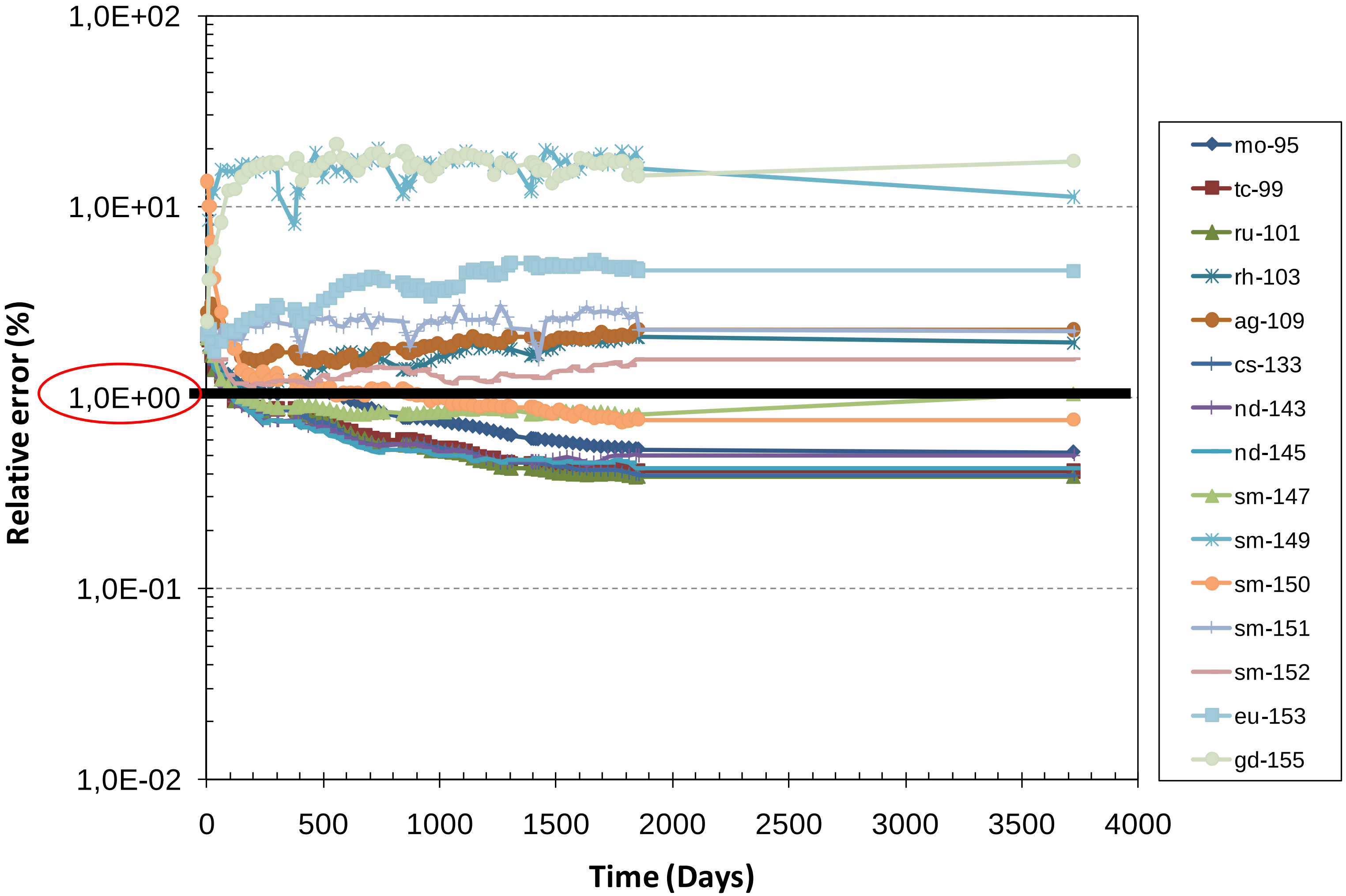
ΔN/N due to XS: Actinides

- ΔN/N (%) predicted with Hybrid Monte Carlo Method due to **uncertainties in XSs** (SCALE6.0/UN)



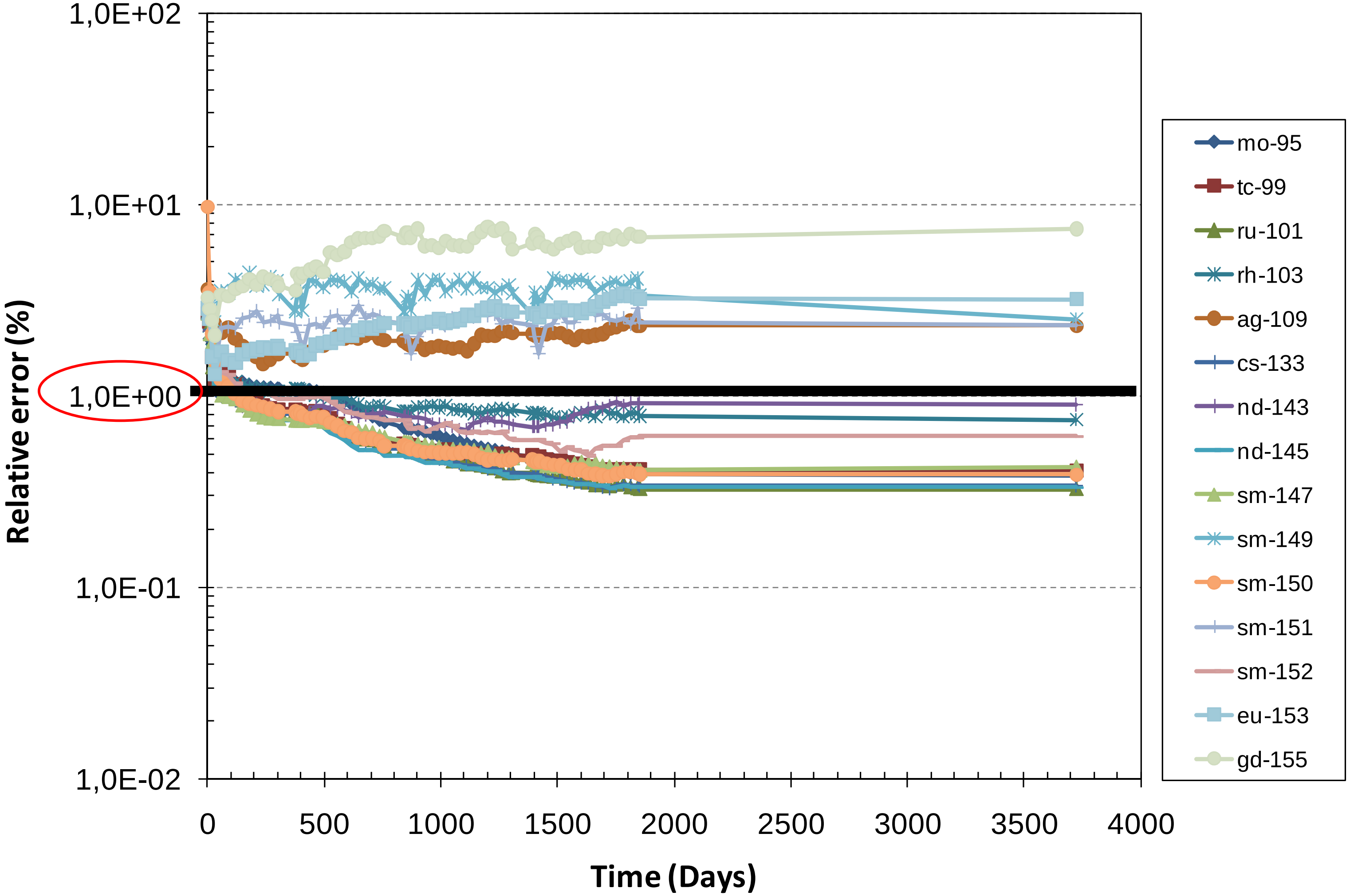
ΔN/N due to XS: Fission Products

- ΔN/N (%) predicted with Hybrid Monte Carlo Method due to **uncertainties in XSs** (EAF2007/UN)



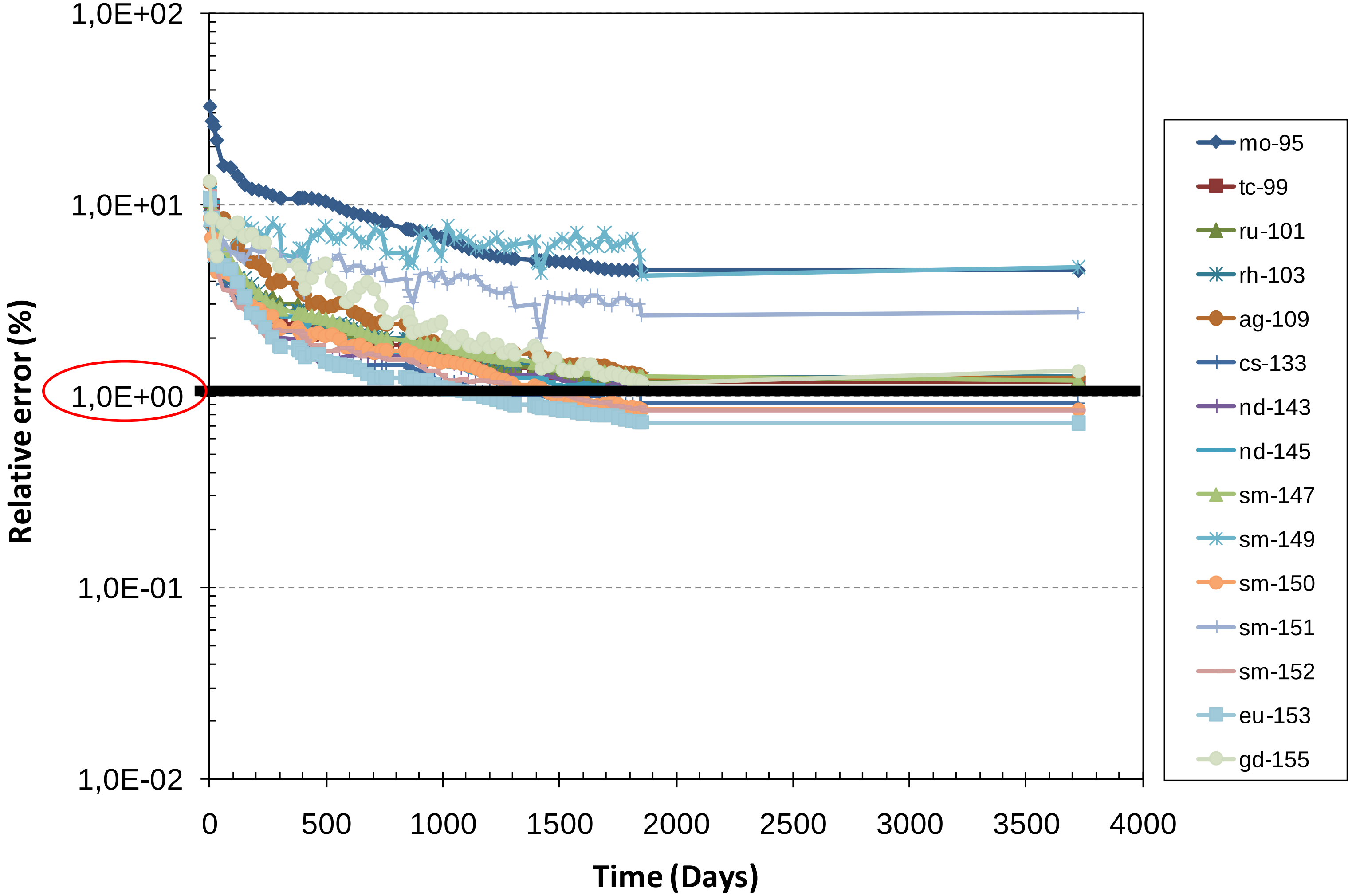
ΔN/N due to XS: Fission Products

- ΔN/N (%) predicted with Hybrid Monte Carlo Method due to **uncertainties in XSs** (SCALE6.0/COVA)



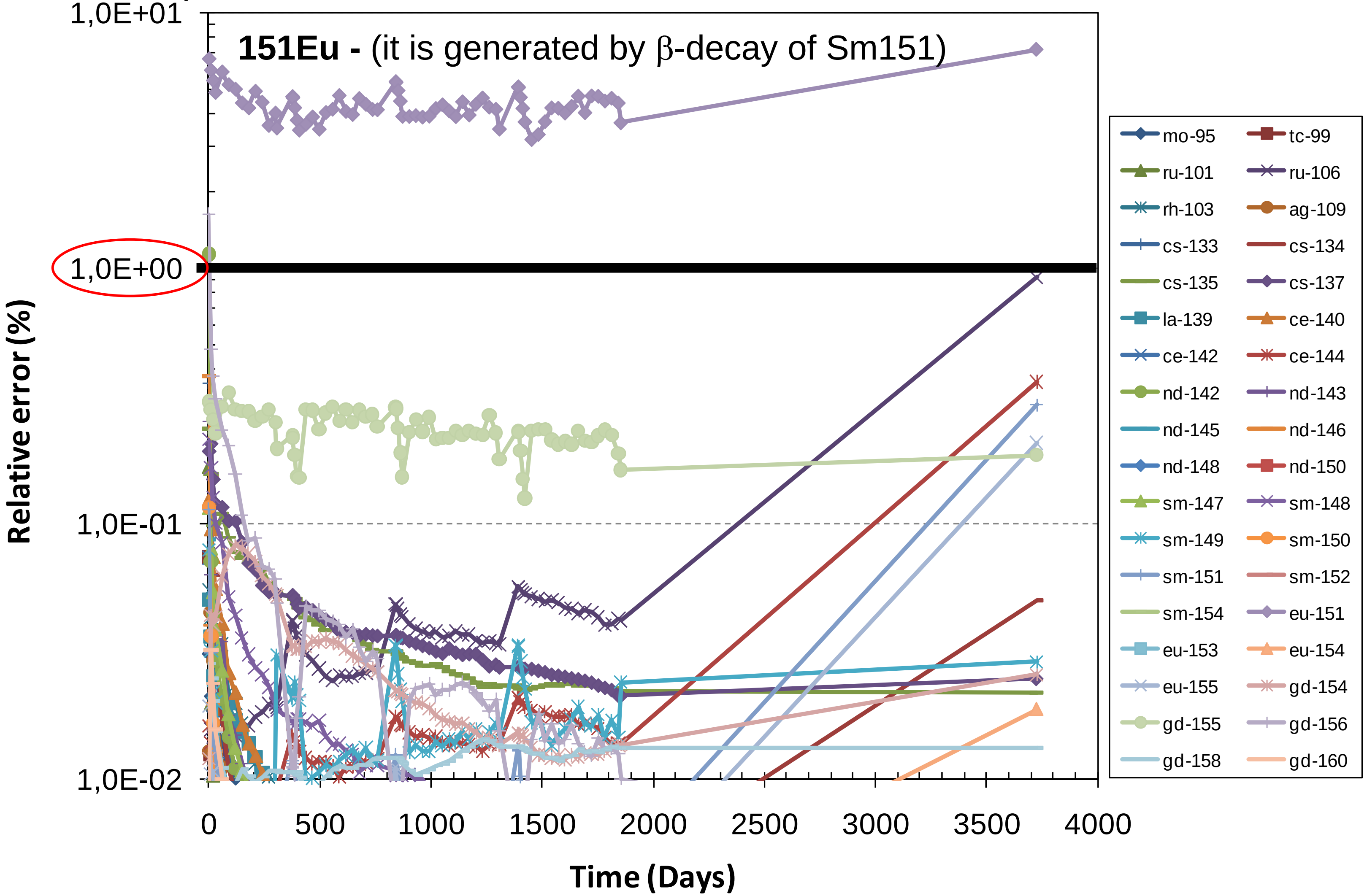
ΔN/N due to Fission Yields: FPs

- ΔN/N (%) predicted with Hybrid Monte Carlo Method due to **uncertainties in FYs** (JEFF-3.1.1)



ΔN/N due to Decay Data: FPs

- ΔN/N (%) predicted with Hybrid Monte Carlo Method due to **uncertainties in Decay DATA** (JEFF-3.1.1)



4. Conclusion “1st PART”

1. An intercomparison of computer codes and nuclear data in **Phase I-B Burnup Credit Benchmark** was performed. It has provided the ability of the present **state-of-art burnup code systems** and data libraries to predict isotopic concentrations:

   - Large differences are found for actinides: **238Pu and 243Am**, and for light elements: **109Ag, 149Sm and 155Gd**
   - 235U and Pu239 are predicted with a relative low error
   - **JEFF-3.1.1shows a significant improvement for 243Am and 109Ag**
   - MONTEBURNS 2.0 and MCNP-ACAB coupled system reproduce isotopies whose deviations from measured values are in good agreement with the rest of the codes

2. We have presented a methodology based on a **Hybrid Monte Carlo method**, accounts for **the impact in inventory calculations of uncertainties in the basic nuclear data** (cross-section, decay data and fission yields) along the consecutive spectrum-depletion steps:

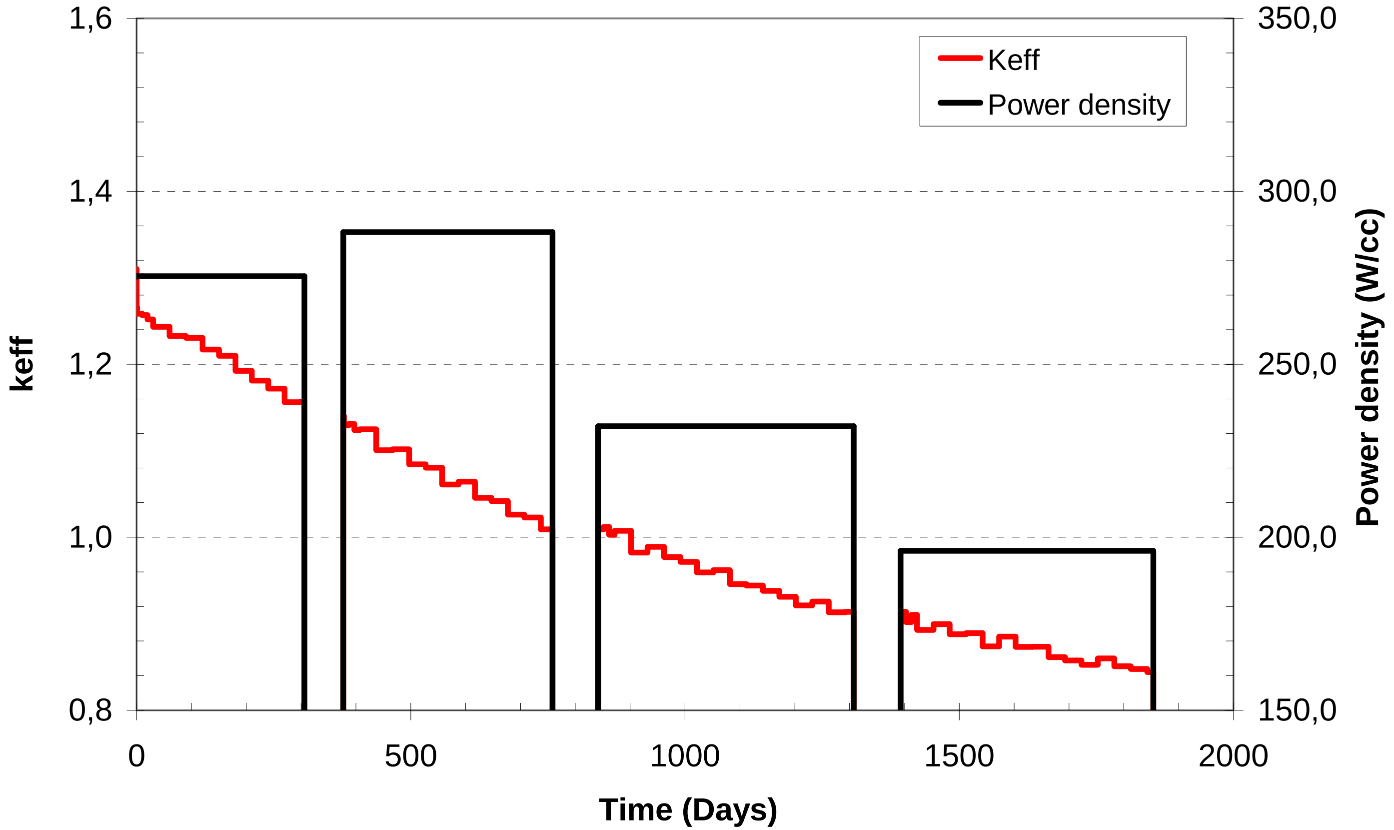
   - In general, **the uncertainty throughout irradiation period rises**
   - Major actinides, uncertainty **remains below 2%** and it reaches **~5%** for some minor actin.: **cm243**
   - Larger uncertainties for fission products: **Sm149, Eu155 and Gd155** were found

   We have evaluated the impact of uncertainties in basic nuclear data, we have obtained:

     - **Decay Data:** Cm243 (0.8%), Ru106(0.9%) and Eu155(7.1%)
     - **Fission Yield:** Mo95(4.5%) and Sm149(4.7%)
     - **Cross-Section:** Cms and Cfs (> 3%), Sm149, Eu155 and Gd155(> 5%)

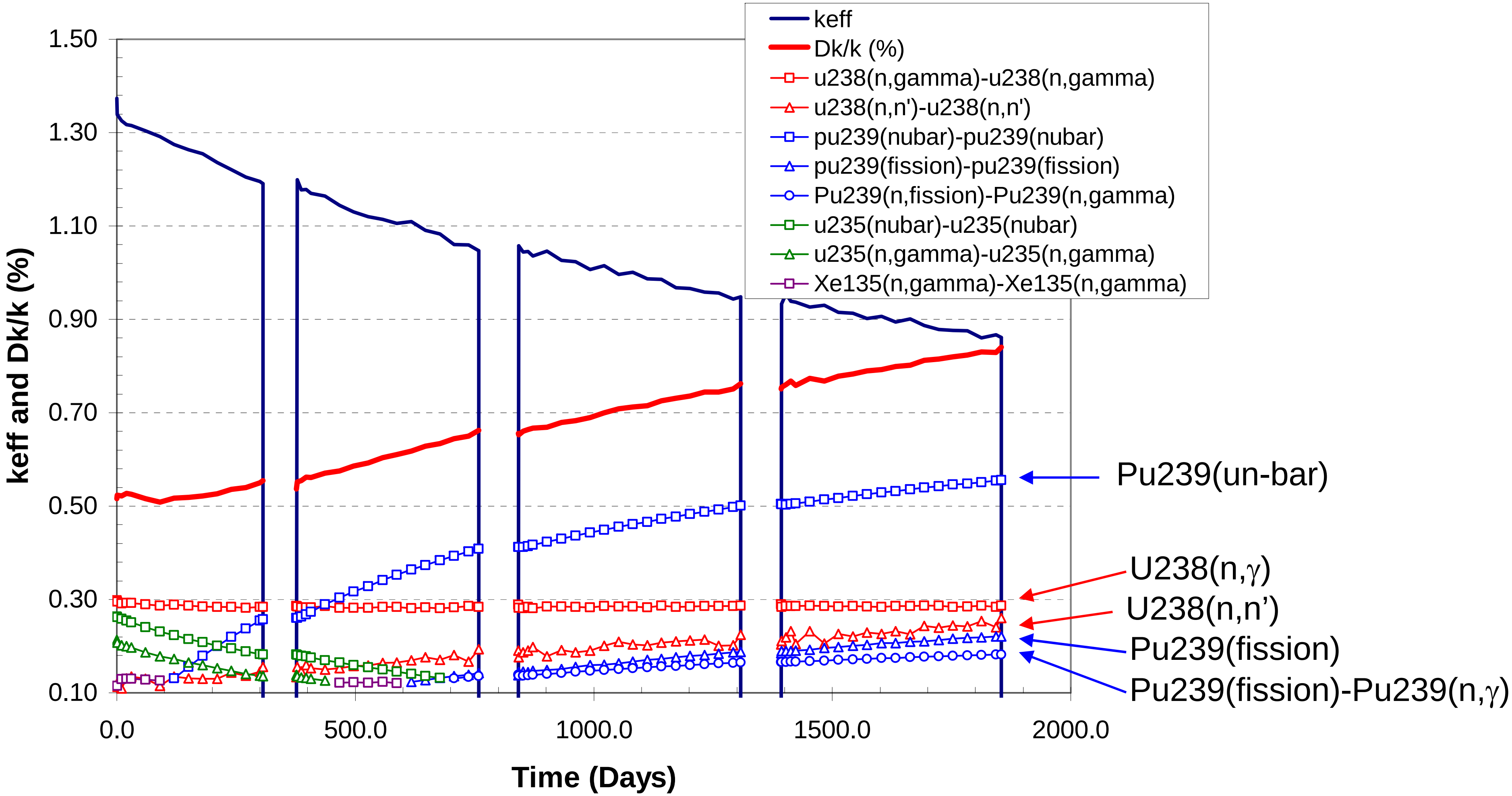
5. Criticality Uncertainty Analysis within "NEA/OECD UAM Project "

- Phase I-B Burnup: 4 cycles (case C). Burnup ~ 44 GWd/TMU
- Neutron transport - inventory/depletion coupling: time step, statistical errors, …



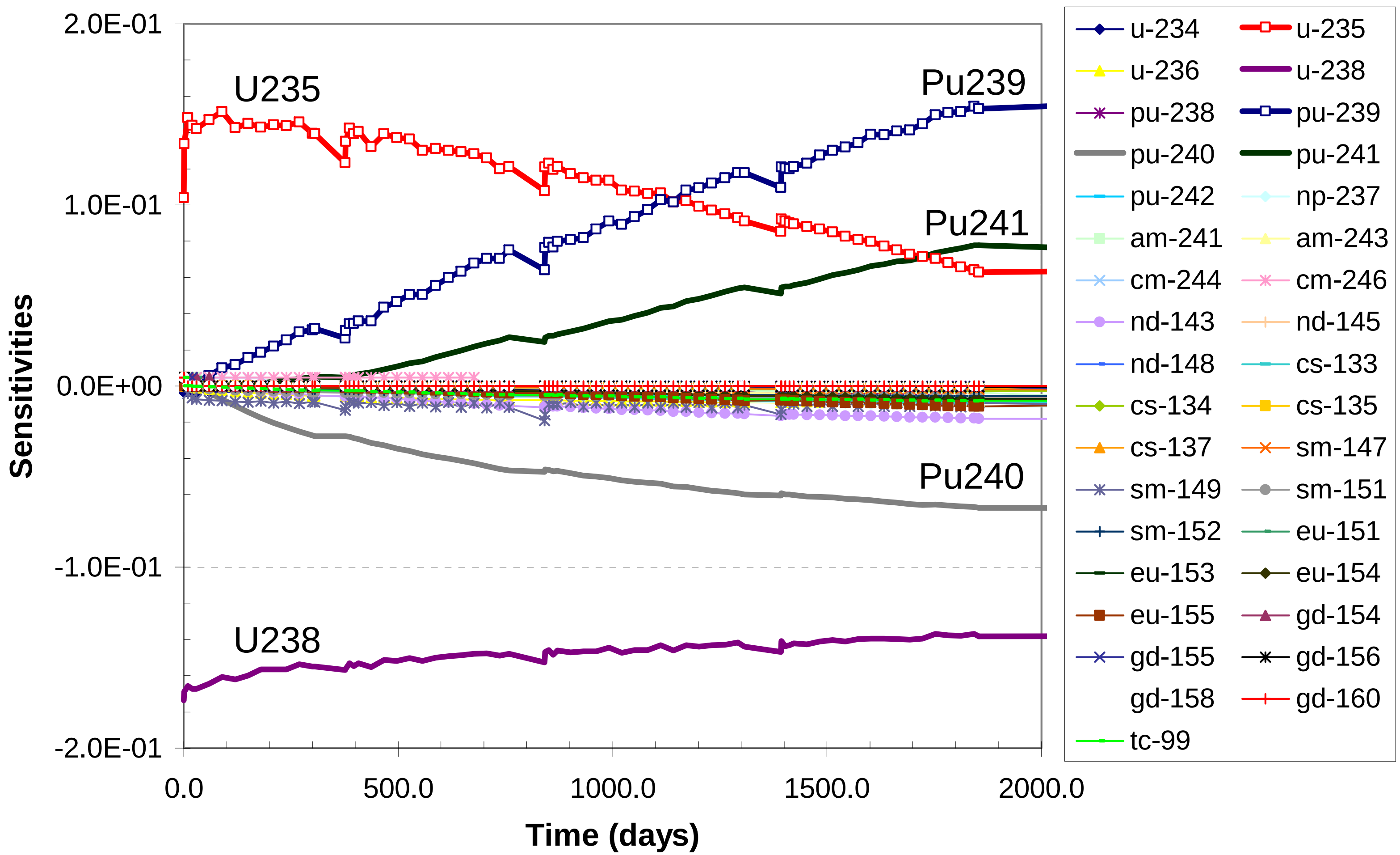
5.1 Prediction of Δk/k - SCALE/TSUNAMI

- Δk/k (%) predicted with SCALE6.0/TSUNAMI and the most important contributions
- In this figure, NO uncertainties in the isotopic inventory are taking into account!!



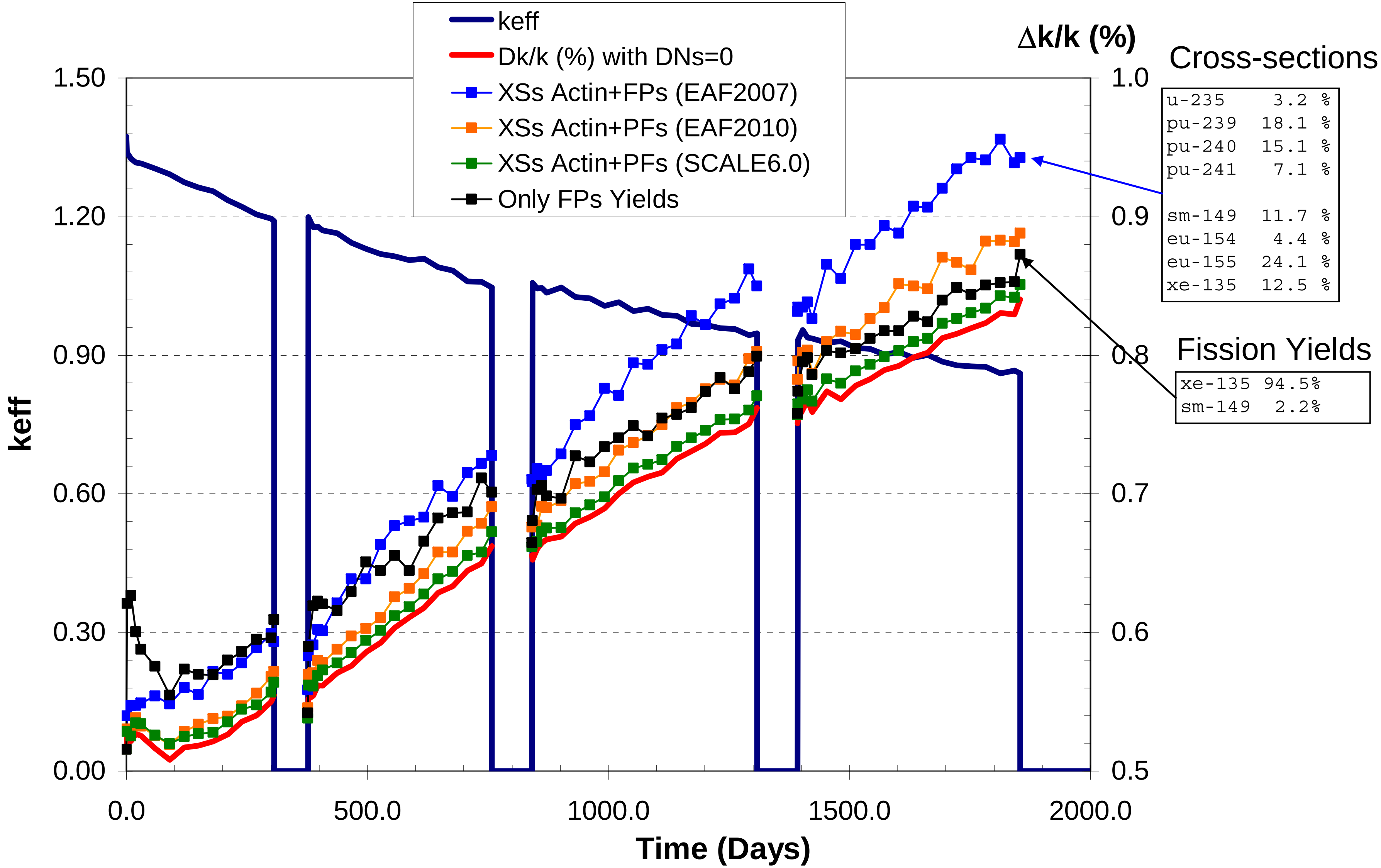
5.2 Sensitivities (Δk/k /ΔN/N): TSUNAMI

- Sensitivitye (Δk/k/ΔN/N) predicted with TSUNAMI (SCALE6.0) and the most important contributions by isotopes



5.3 Prediction of Δk/k due to ΔN/N

- Δk/k (%) due to the uncertainties in the isotopic inventory



6. Conclusion "2nd PART"

We have carried out a ***Burnup Criticality Uncertainty Analysis*** for the Phase I-B -HFP Benchmark (Burnup ~ **44 GWd/TMU**)

1) Assuming **no uncertainties in the isotopic inventory**, TSUNAMI/SCALE6.0 predicts Δk/k (%) at BOC:~ 0.5% and EOC :~ 0.8%

   At EOC, the most important reactions are: Pu239(nubar), U238(n,gamma), U238(n,n'), Pu239(fission) and Pu239(fission-capture)

2) To take into account **uncertainties in the isotopic inventory**, an Hybrid Monte-Carlo methodology that links transport and inventory calculations is presented

   It enables to estimate the impact of nuclear data (neutron cross section and fission yields) uncertainties on the inventory in transport-burnup combined problems.

At EOC, we predict the values of Δk/k (%) due to ΔN/N:

- **EAF2007/UN**: XSs for actinides:~ 0.3% and for fission products :~ 0.2%
  The most important isotopes:Pu239 and P240; Eu-155, Xe135 and Sm149
- **EAF2010**: total uncertainty (ACTINIDES+FPS):~ 0.30%
- **SCALE6.0**: total uncertainty (ACTINIDES+FPS):~ 0.15%
- **Fission yields**: ~ 0.2%. The most important isotopes: Xe135
- **Decay data:** negligible

On going work…

In the framework of UAM/NEA group ("Uncertainty Analysis in Modelling"), we are discussing a Benchmark exercise (TMI-Pin cell) in order to compare different current **uncertainty burnup methodologies**:

- NRG/Total Monte Carlo
- AREVA/NUDUNA
- GRS/XSUSA
- UPM/Hybrid Monte Carlo
- …?¿

Results will be presented in the next UAM Meeting (UAM6) May 2012 in KIT (Germany)

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Acknowledgments

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